Avoiding Injury Through Human-Capable Design

Author

Don Goddard, M.S., RPT

US Army Center for Health Promotion & Preventive Medicine

Presenter

Mark Geiger, M.S.E., CIH, CSP

Chief of Naval Operations N09FB

Safety Liaison Office, Arlington, VA

Ergonomics and materials handling

- A key area for acquisition planning
- Human Systems Integration (HSI) is a part of acquisition requirements (DoD5000.2)
- Source of many mishaps and occupational illnesses
- Potential approach to improving safety and reducing manpower

ERGONOMICS AFFECTS THE NAVY

Other Services Likely to be Similarly Impacted

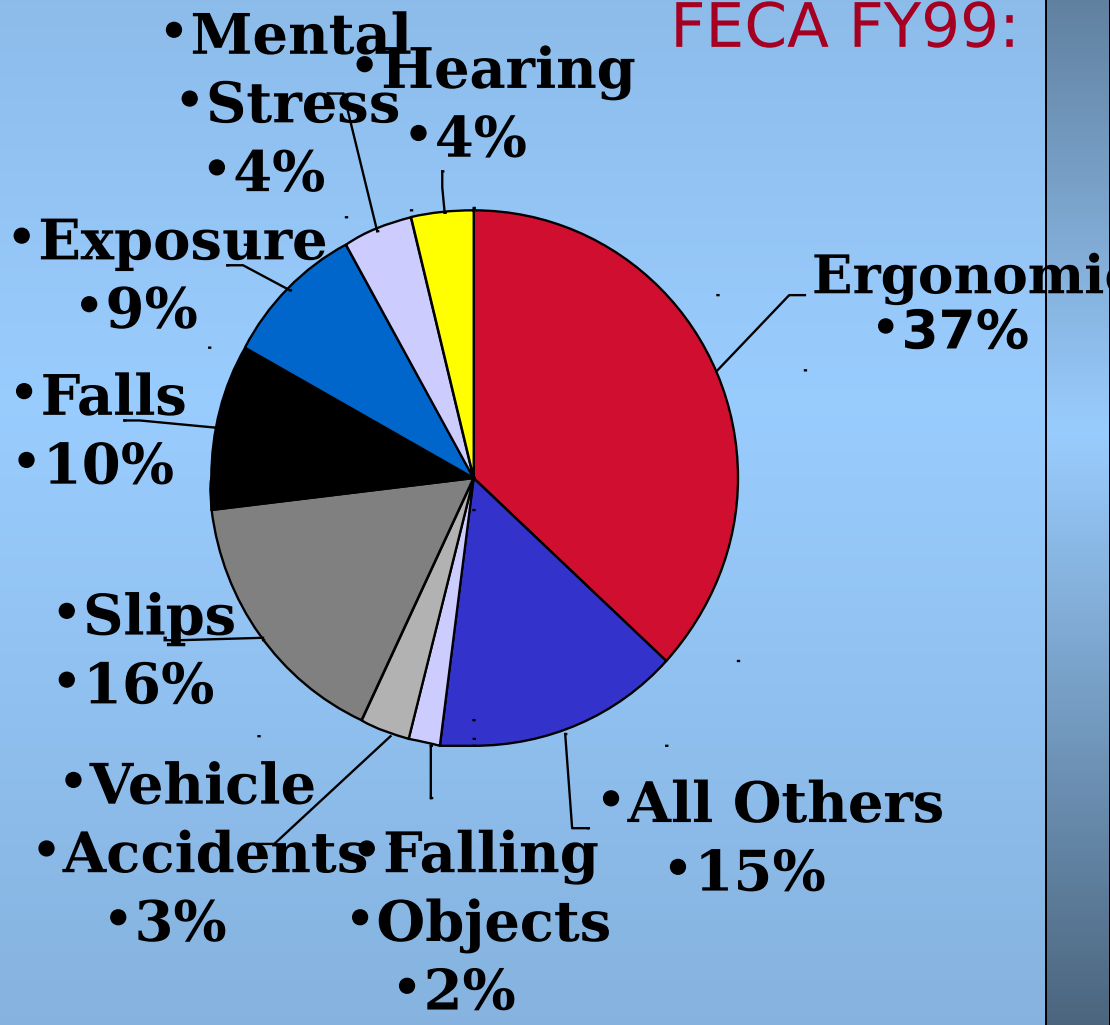
Ergonomic injuries and illnesses*

- Represent the single largest source of claims and costs to the Navy
- Roughly $90 million annually or one-third of all recent claims

If left unchecked, the Navy's annual cost is

- Projected to increase to $111 million by FY 2009.

* **Analyzing the Navy's Safety Data by CNA, December 2001**



What is Human-Capable Design?

Creating products that expose users to less mechanical stress in order to:

- Decrease risk of operator injury
- Increase operator performance (efficiency)
- Allow operators to safely and comfortably interact with products longer

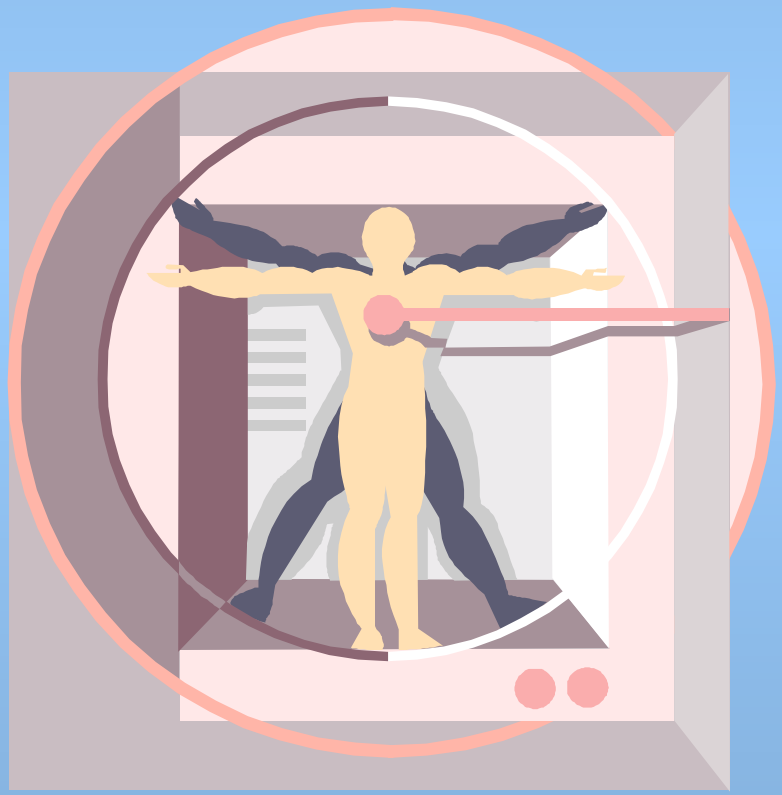
How is this accomplished now?

System Safety reviews:

- Conducted during design phase of the product development cycle
- Strive to identify and mitigate injury risks before products are deployed
- Alternative is expensive retro-fits

System Safety and Human Systems Integration (HSI)

- Both require risk identification
- System safety has focused on risks to systems
- Human Systems Integration focus on design for user



How is this accomplished now?

- **System Safety reviews tend to rely upon standardized System Safety methods and techniques**
  - Tendency to focus on equipment failure
  - Considers risk of injury to human
  - May not optimize design to avoid features that compromise human performance

System Safety Methods & Techniques

Methods & Techniques Employed

- Preliminary Hazard Analysis
- Failure Mode and Effect Analysis
- Fault Tree Analysis
- Management Oversight & Risk Tree
- Energy Trace and Barrier Analysis

System Safety Methods & Techniques

Struggle to Capture the "Human Side"

- Analyses are not structured in a way that obligates users to consider long term effects on human operators
  - Tend to be "product-oriented" at the expense of the human system component
- Deficiencies force users to make assumptions about injury risk

System Safety Methods & Techniques

Typical Product Specification

- **Product-Oriented Description**

Hand Winch

- **Lift capacity: 1.1 tons**
- **Rope capacity: 85 ft**
- **Operating force requirements: 54 lbs**

“Human-Capability” Questions

•Is the user population able to generate 54 lbs?

•What is the injury risk for weaker operators?

System Safety Methods & Techniques

Limitations of Approach

- **System Safety tools dependent upon assessor's knowledge of human capabilities**
  - Assessment tools don't provide references that fill knowledge gaps
  - Less knowledgeable assessors must develop inferences about product injury risks that are sometimes based upon faulty assumptions

System Safety Methods & Techniques

Weakness of Approach

- People performing System Safety reviews tend to have limited knowledge of human capabilities
- Commonly used tools do not always fill the gaps in knowledge

System Safety Methods & Techniques

Evidence of Weakness of Approach

- Authors concluded that designers often fail to foresee the health risks in the activities associated with the intended use of their products
- Advocated a task-based risk assessment approach using a hazard list that includes ergonomics

System Safety Methods & Techniques

Evidence of Weakness of Approach

- Study found an average of 5 Human Factors design problems in each product reviewed
  - Domains included physical & cognitive workload
- Recommended adhering to a “user-centered” design approach

System Safety Methods & Techniques

Evidence of Weakness of Approach

- Authors advocate “cradle to grave” integration of safety and design that includes:
  - Implementing Ergonomics Pro-actively
  - Developing Better Contract Specifications
  - Educating Purchasers

Common System Design Errors

- Excessive Muscular Exertion
  - Manual Material Handling Demands
  - Pushing-Pulling Demands
  - Grasp & e Demands

Common System Design Errors

- Example: Excessive MMH Demands
  - Army Mobile Analysis System

Original	Current
402 lb	275 lb
313 lb	200 lb
	100 lb
	65 lb
715 lb	640 lb

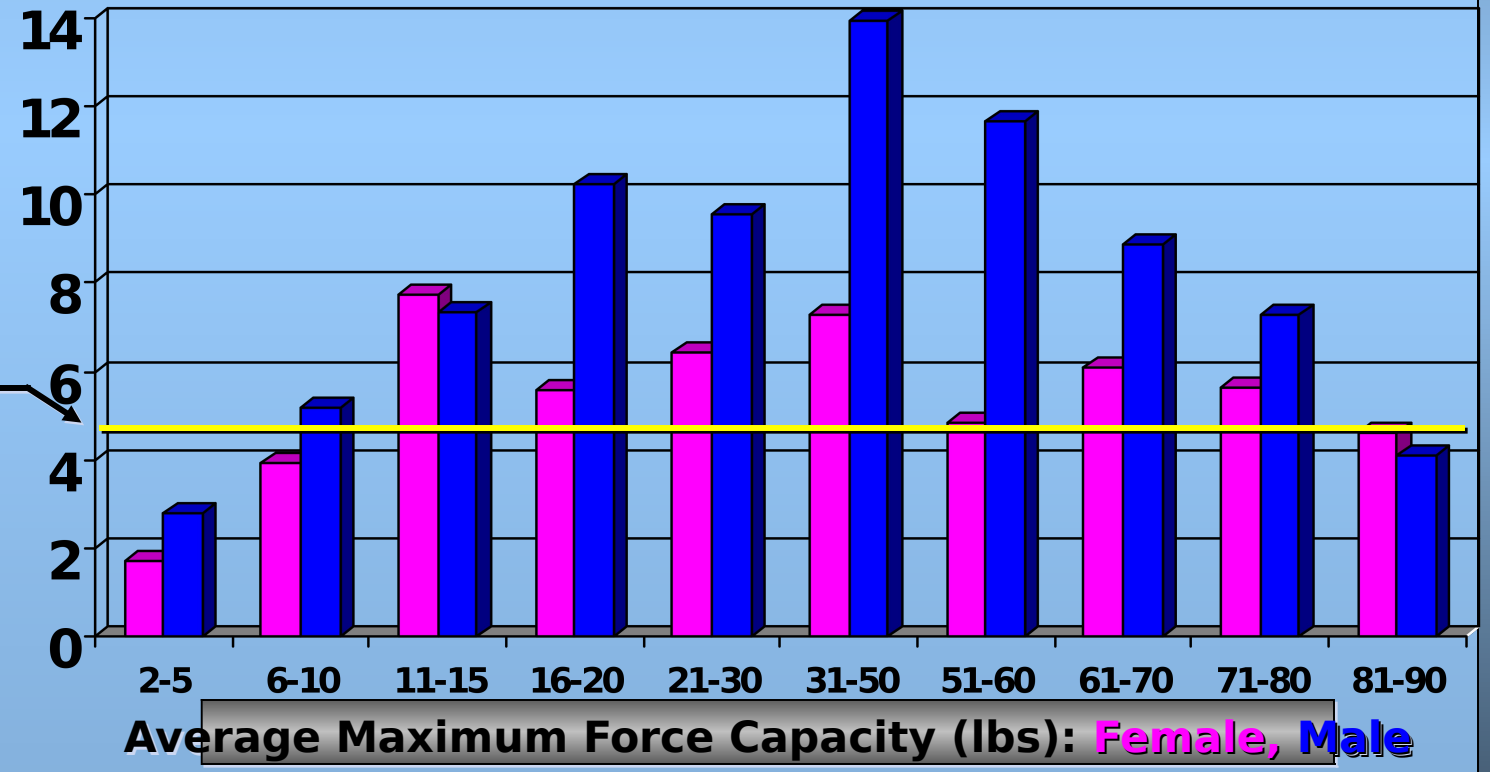
Note: Max Allowable Weight for 4 person team:

All Male Team – 305 lbs; Mixed Team –

Common System Design Errors

- Example: Excessive Pull Demands
  - Drink Can Pulling Force Demands

Force Required To Open Can 4.6 lbs.



Common System Design Errors

Excessive Extrinsic Load

- Load Carriage
- Head Supported Mass*

  - The head is about the size and weight of a bowling ball

Common System Design Errors

- Example: Excessive Load Carriage
  - Heavy Army Field Infantry Load

Soldiers Expected to Carry Heavy Equipment Load

Common System Design Errors

Example: Excessive Load Carriage

Position	Ave FL[1]	FL %BW	Ave AML[2]	AML %BW	Ave EAML[3]	EAML %BW
Rifleman	63 lb	36%	95.7	55%	127.3	71%
M240B Ammo Bearer	69 lb	37%	117 lb	62%	144 lb	80%

[1]FL = Fighting Load
[2]AML = Approach March Load
[3]EAML = Emergency Approach March Load

Many new acquisitions are conceived as “add-ons” to this “baseline” load

Common System Design Errors

Example: Excessive Load Carriage

- Military Headgear Design

- Wearing heavy gear of long durations may elevate the risk of cervical injury

- Asymmetrically distributed load can cause fatigue and increase cervical injury risk

Common System Design Errors

Excessive Metabolic Demand

- Regional Fatigue
  - Overusing smaller muscles within a specific region of the body
- Systemic Fatigue
  - Overusing larger muscles from multiple body regions
    - Activity stresses heart & lungs
    - Heat stress may contribute to overall metabolic load

Common System Design Errors

Example: Excessive Metabolic Demand

- Many DoD personnel perform jobs with high cardiopulmonary demands
- Demands increase further during deployed military operations
  - Have been associated with increased musculoskeletal injury risk (MIR)
  - **MIR ↑ 7.6 times for personnel constructing deployed bases**

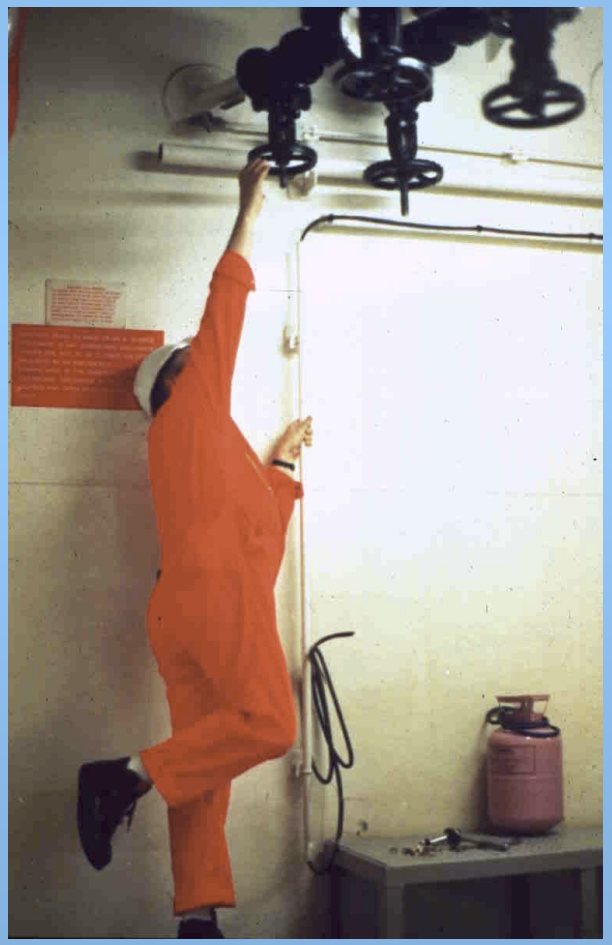
Common System Design Errors

Dimensional Incompatibility

- Sizing
  - Human-Machine Couplings
    - Control Points (handles)
    - Other Couplings (i.e., seatpans)
  - Wearables (headgear & clothes)
- Accesses (doors/hatches & portals)
- Reaches (arms & legs)

Common System Design Errors

Example: Human-Machine Coupling



Photos courtesy of Gerry Miller

Common System Design Errors

Example: Human-Machine Coupling

Photos courtesy of Gerry Miller

Military Vehicle with Retrofitted Ladder

Photo courtesy of Trailormate
http://www.trailormate.com

- **Step-off distance in various military vehicle is in the range of <u>4 to 6 feet.</u>**
- **The ladder is a retrofit!**
- **Imagine doing this in a vulnerable combat situation with a 80 pound pack!**

Common System Design Errors

Example: Human-Machine Coupling

- This is a first design of what device?

Computer Mouse

Common System Design Errors

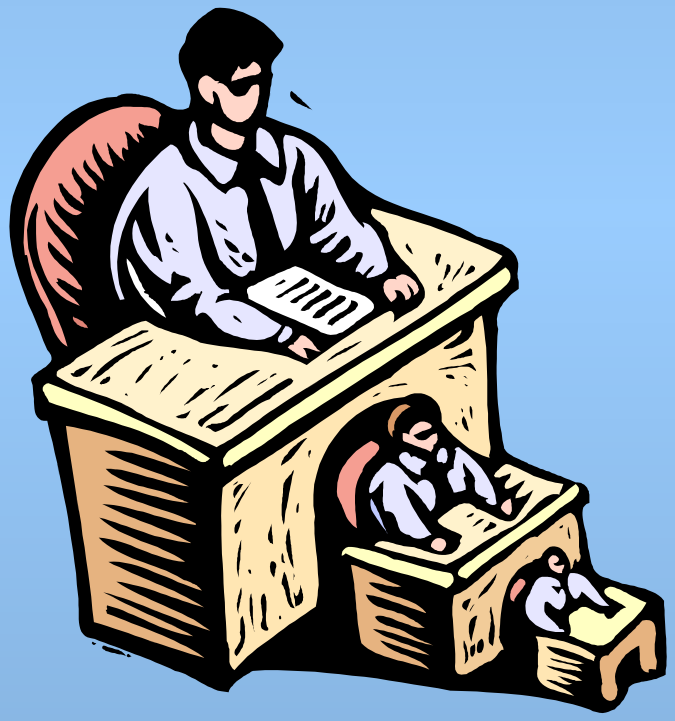
Example: Human-Machine Coupling

- Hand-Tool Size Mismatch

Handles get smaller, but hand does not

Smaller handles are difficult to use by normal-sized hands

Do we need different size operators to use each task or tool?



Common System Design Errors

- Example: Size of Wearables
  - Product Size Mismatch

Wrong-sized apparel frustrates users

Common System Design Errors

Example: Access Dimensions

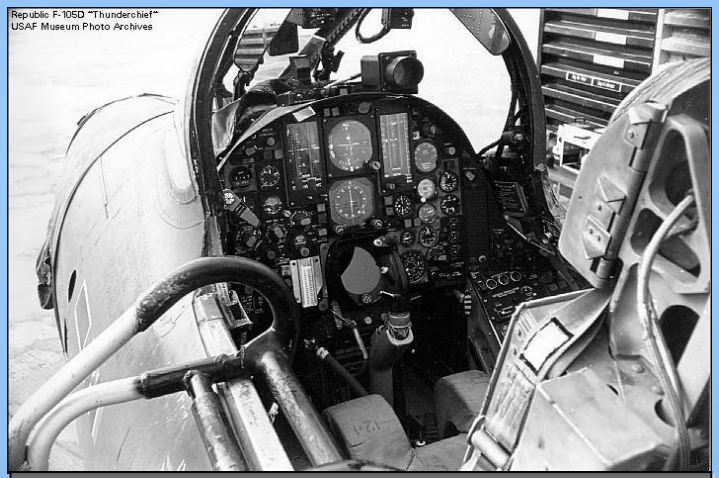
- Wrong-sized Opening

Head may strike handle while trying to exit vehicle

Common System Design Errors

Example: Access Dimensions Problem

- Inadequate Clearance



F105D "Sample" Cockpit

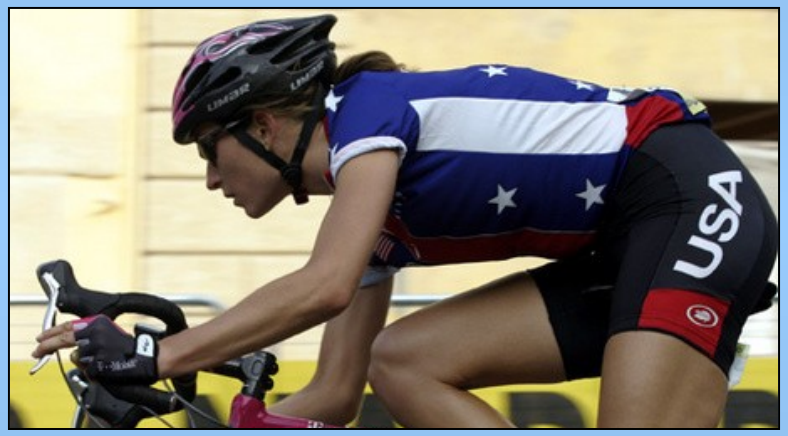
Pilots Killed Ejecting From F-104A

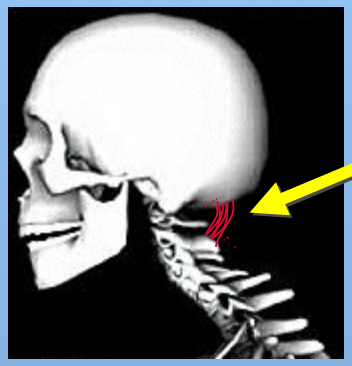
- **Cause: Bad Seat Design**
- **Detail: pilot's knees would not clear the forward canopy edge due to the fact that the parachute placement positioned the pilot too far forward**
- **Solution: The model DQ-7 seat was replaced with a redesigned GQ-H7 seat that allowed clearance**

Common System Design Errors

Example: Poor Workstation Design

- **Excessive Reach Requirement**





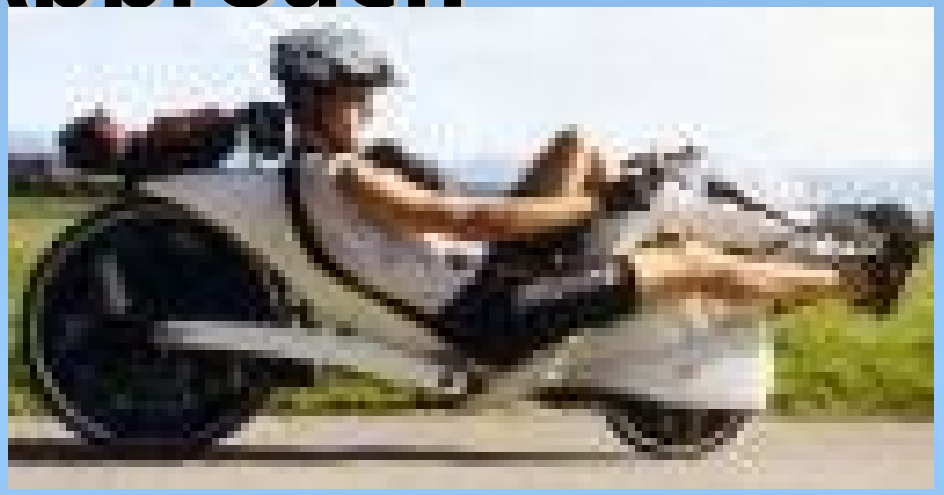
Shortened muscles compress nerve

Bike Design Causes Headaches

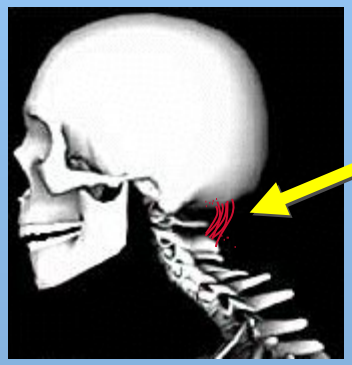
- **Cause: Bicycle "Workstation" Design**
- **Detail: Chronic extended neck posturing shortens muscle in back of neck, increases pressure on suboccipital nerve, and may cause headaches & disc disease**
- **Solution: Ride a bicycle that allows upright spinal posture**

Common System Design Errors Avoided by New Approach

springdalebicycle.com/Why_Recumbant.htm



http://www.kreuzotter.de/



Shortened muscles compress nerve

Common System Design Errors

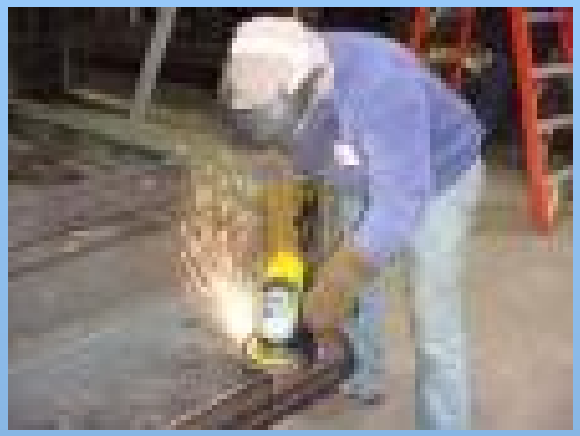
- Example: Poor Workstation Design
  - Excessive Reach Requirement

Difficult pinning papers located beyond reach envelope

Common System Design Errors

Extrinsic Mechanical Energy Exposure

- Hand Arm Vibration (HAV)
- Whole Body Vibration (WBV)



•www.osha.gov/.../hot_work_welding.html

Common System Design Errors

Example: Excessive HAV Exposure

Manual Soil Plate Compactor

Exposure Characteristics

Acceleration: 7.3 m/s²

Exposure Limit: 120 min/day

Compactor Transfers Vibration to Operator's Hands

Mitigation efforts (equipment redesign, equipment substitution, process redesign) unknown –
See this afternoon's presentation by Nancy

Common System Design Errors

Example: Excessive WBV Exposure

Construction Equipment

Exposure Limits	
Paved Road:	30 min
Gravel Road:	105 min
Cross-Country:	410 min

Vehicle Transfers WBV Through Body Contact Points

Mitigation efforts (equipment redesign, equipment substitution, process redesign) unknown

See this afternoon's presentation by LT

Typical Life Cycle Costs in Acquisition

Commit to Human Systems Integration

Implement Human Systems Integration efforts throughout the product's entire lifespan

60-70% Operations, Maintenance & Disposal | **20-30% Procurement** | **10% R&D**

- *70% of costs committed in preliminary desig*

Operations & Support	Production & Deployment	System Development & Demonstration	Technology Development	Concept Refinement

Requirements for Life-cycle Safety

- **DoDI 5000.2 Operation of the Defense Acquisition System May 12, 2003**

3.9.2 <u>Sustainment</u>

Effective sustainment of weapon systems begins with the design and development of reliable and maintainable systems through the continuous application of a robust systems engineering methodology. As a part of this process, the PM shall employ human factors engineering to design systems that require minimal manpower; provide effective training; *<u>can be operated and maintained by users</u>*; and are *<u>suitable (habitable and safe with minimal environmental and occupational health hazards)</u>* and survivable (for both the crew and equipment).

Requirements for Life-cycle Safety

U.S. Navy Photo by Photographer's Mate 2nd Class Bradley J. Sapp (RELEASED) For more information go to: http://www.cpf.navy.mil/RIMPAC2004

DODI 5000.2 Operation of the Defense Acquisition System

May 12, 2003

3.9.2 Sustainment

The PM shall employ human factors engineering to design systems that require minimal manpower; provide effective training; can be operated and maintained by users; and are suitable (habitable and safe with minimal environmental and occupational health hazards) and survivable (for both the crew and equipment).

How Can The Process Be Improved?

Educate Key Players in Ergonomics

- Increase acuity of recognition of job demand/worker physical capacity mismatches
- Improve problem-solving skills relevant to mitigating potential health risks due to mismatches between job demands & worker physical capacity

How Can The Process Be Improved?

Develop Better Risk Assessment Tools

- Based on Human Capability and Exposure Tolerance Limits for these Common Problem Areas:
  - Excessive Muscular Exertion
  - Extrinsic External Load
  - Excessive Metabolic Demand
  - Dimensional Incompatibility
  - Extrinsic Mechanical Energy Exposure

How Can The Process Be Improved?

Develop Better Risk Assessment Tools

- Design engineers can use them to guide decisions during early product development

How Can The Process Be Improved?

Stop Buying High-Risk Products

- Purchase of high-risk products is reduced through awareness education and risk assessment
- Decision-makers are provided an assessment tool that identifies high risk product characteristics that should be considered before purchase

Examples

Procurement of Heavy Vehicle

Risk Analysis Reveals Following:

- **Vehicle operation exposes personnel to whole body vibration**
  - **Purchase decision should consider injury risk based upon existing standards**

Whole-Body Vibration Exposure Assessment Matrix*

Daily Exposure (Hours)	Value of the Dominant, Frequency-Weighted (rms) Component Acceleration in m/s^2		
	No Effect Clear	Caution Zone	Health Risk Likely
2	Less than 0.9	0.9 to 0.6	Greater than 1.6
4	Less than 0.6	0.6 to 1.1	Greater than 1.6
8	Less than 0.5	0.5 to 0.9	Greater than 1.6

*Based on equation B.1 of ISO 2631-1: 1997

Procurement of Heavy Vehicle

- Vehicle maintenance exposes personnel to ergonomics hazards
  - Purchase decision should apply an assessment tool that considers ergonomics injur

Navy Ergonomics

Facility Maintenance

Manual Process Annual Cost	45.9K	
Improved Process Annual Cost		22.7K
Annual Cost Difference (Savings)		22.8K
Tool Purchase Price (5 units)		14.5K
Return on investment (10 yr. service life)		
Cost Savings	213K	
Break Even Point		232 Days

No injuries since inception

TYPICAL AIRCRAFT CARRIER DEEP TANK REFURBISHING OPERATION
COST AVOIDANCE ASSOCIATED WITH IMPROVED ACCESS

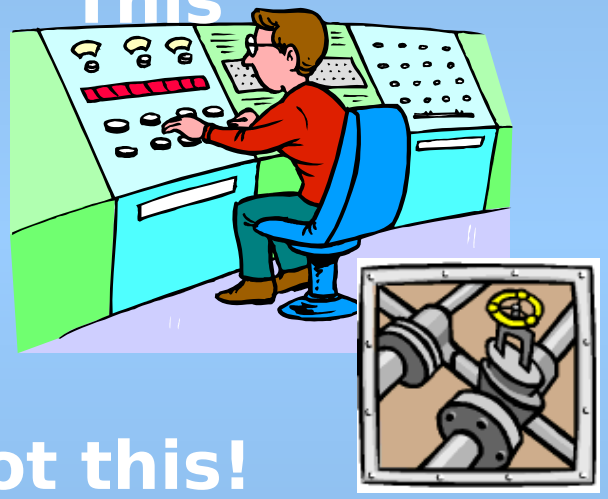
	Present	Present	Proposed	Proposed	Savings	Savings
Number of entries/ personnel	Work time (hours)	Cost ($60/hr)	Work time	Cost ($60/hr)	Work time (hours)	Cost ($60/hr)
42	88	$21.2K	**55**	**$13.3**	**32**	**$7.9K**

Savings $250,000 per shipyard period, $2,500,000 lifecycle

System Safety protects USERs

Those often unable to influence system design
(Also protects the taxpayers)

This



Not this!

- **Identifies risks in prior systems**
- **Requires that controls be built into the design**
- **Minimizes later work-around**
  - **Training**
  - **Protective equipment**
  - **Complex procedures**
- **Reduces maintenance and disposal costs**

Resources

Service Ergonomics Programs

- **DOD Ergonomics Working Group**

http://www.ergoworkinggroup.org/

Air Force Occupational and Ergonomics Program

http://www.brooks.af.mil/afioh/Health%20Programs/ergonomics_links.htm

- **Crew System Ergonomics Information Analysis Center**

- **http://cseriac.flight.wpafb.af.mil/**

Service Ergonomics Programs

Navy- Acquisition Website

www.safetycenter.navy.mil/acquisition

http://www.safetycenter.navy.mil/presentations/osh/previewimages/ergonomics4.gif

Ergonomics program

OPNAVINST5100.23 Chapter 23 Ergonomics

NAVSEAINST 3900.08A
Date 20 May 2005 Subject HUMAN SYSTEMS INTEGRATION (HSI) POLICY IN ACQUISITION AND MODERNIZATION

Service Ergonomics Programs

Army Ergonomics Overview

http://www.cs.amedd.army.mil/iso/IntroErgonomics/Default.htm

US Army Center for Health Promotion and Preventive Medicine

http://chppm-www.apgea.army.mil/dohs/

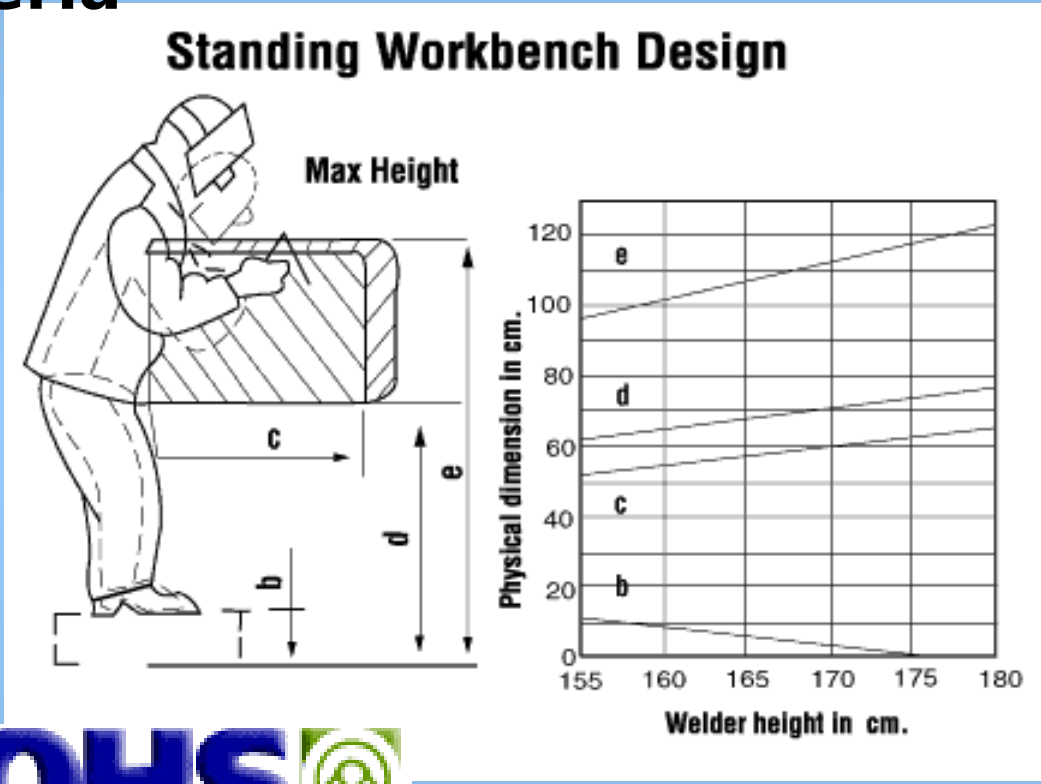
Health Hazard Assessment Program

http://chppm-www.apgea.army.mil/dohs/hha/HHAPocketGuide.pdf

Manprint Program

http://www.manprint.army.mil/manprint/

- **Example of Common Task Design Criteria**



CCOHS
Canadian Centre for Occupational Health and Safety

- **www.ccohs.ca/.../ welding/ergonomics.html**

Field Tools

Most are simple

Angle measure

Scale

Gauge for pulling stress

- **www.jacks.co.nz/measuring_length__moisture.html**

Contact Information

Don Goddard, M.S., RPT
US Army Center for Health Promotion & Preventive Medicine
don.goddard@us.army.mil

Mark Geiger, M.S.E., CIH, CSP
Chief of Naval Operations N09FB
Safety Liaison Office, Arlington, VA
Mark.Geiger1@navy.mil
703 602-5020